Introduction

Scientific Input and Study Design

Several National Park Service units in the Intermountain region possess a number of closely related management needs relative to the abundance of wild ungulates and their herbivory effects on plants and ecosystem processes. In 1993, the then National Biological Service (NBS) – now U.S. Geological Survey, Biological Resources Discipline (USGS, BRD) – initiated a series of research studies in four park units in the Intermountain West, into the abundance and effects of ungulates on park ecosystems. Each of these parks received a number of similar research study elements including: (a) a number of new ungulate grazing exclosures (n = 12–21 exclosures per park); (b) aerial survey sightability models to estimate population sizes of ungulates; (c) measures of biomass production and consumption rates near the exclosures and across the landscape; (d) studies of the effects of the grazing on plant abundance, species diversity, and ecosystem effects; and (e) computer model simulations (SAVANNA) of the effects on the ecosystem and plant resources of different ungulate management scenarios. One park unit, Rocky Mountain National Park, Colorado, received funding from the U.S. Geological Survey (USGS, BRD) and parallel funding from NPS for an intensive research study of the effects of elk on the park ecosystems.

Elk were extirpated, or nearly so, from Rocky Mountain National Park by human exploitation in the late 1800s, but were then reintroduced in 1913 and 1914. Elk steadily increased until they reached an estimated 1,000 animals within the park boundaries in 1944 (Packard 1947). Due to concerns over increasing elk numbers and potential effects on the park winter range, elk in the park were artificially reduced from 1943–1968. During this period, a total of 1,664 elk were removed from the park with the goal of reducing the park herd to about 500 on the eastern boundary winter range. In 1968 elk were no longer controlled within the park's boundaries with a NPS change in management policy to one of natural regulation that occurred in Yellowstone National Park at the same time. From 1968 to the present time, herd limitation was attempted through natural regulation within the park and harvests outside of the park. Interagency goals of the NPS, Colorado Division of Wildlife (CDOW), and U.S. Forest Service (USFS) included use of both regular and late season hunts outside of the park boundaries to limit the elk population by harvesting 500–600 elk each year. The harvest goal was nearly achieved prior to 1987 when an average of 442 ± 78 elk were harvested each year, but after 1987, increasing restrictions to private lands outside the park reduced the harvest. Elk harvests declined to 302 ± 36 after 1987. In either case, these harvests were insufficient to limit the growth of the elk population and elk steadily increased in the park and then later in the town of Estes Park. Concerns over possibly overabundant elk resulted in criticisms of the park elk policy (Hess 1993) and calls for the agencies to reevaluate their interagency elk management efforts. In 1993, the park superintendent, James Thompson, requested F. J. Singer of the National Biological Service (now USGS-BRD), to conduct a problem analysis of the elk situation.

The goals of the study included determination of whether elk densities had exceeded those expected in a natural system, whether unnatural concentrations of elk were occurring, what the effects of elk herbivory were, and whether the effects of the elk herbivory were acceptable or unacceptable. At the onset of the study, it was recognized that a number of human influences had occurred in the system that might confound the interpretation of the effects of elk alone. For example, any climate change or unnatural succession due to fire suppression might have influenced plant communities. A number of meadows in the winter range had been drained for a golf course located in the park until the 1960s and a number of other park meadows had been drained for cultivation. Beaver had apparently declined on at least part of the winter range and for unknown reasons. The presence of the rapidly growing town of Estes Park, located within the edge of the winter range, might have altered or abbreviated elk migrations. The major predators of the system, wolves and grizzly bears, had long since been extirpated and considerable debate and speculation surrounded what their effects might have been on possible limitation of elk.

Study design input included the problem analysis prepared in 1993 and proposals submitted to BRD and the NPS in 1993 by F. Singer, and three peer reviews of the study design conducted in 1994 (Table 1). The study also built upon earlier peer reviews of the similar problem in Yellowstone National Park (Table 1). The study design included key elements of those review suggestions, including: census methodology and demographic analysis of the elk population, studies of vegetative biomass produced in grazed and ungrazed areas and elk offtake, studies of effects on ecosystem processes, GIS-based ecosystem model (SAVANNA) experiments to test hypotheses, and evaluation of grazing effects on plant

Table 1. List of proposals and peer reviews of this study in Rocky Mountain National Park and for the closely related elk management situation in Yellowstone National Park.

Proposals:

Singer, F. J. 1993. Elk-vegetation relationships in Rocky Mountain National Park: A problem analysis of the existing data and recommendations for future research and monitoring. U.S. Department of the Interior, National Park Service, Fort Collins, Colo. 23 pp.

National Biological Service. 1994. Draft work study plan, ungulate-plant interactions in five national parks in the Rocky Mountain region. Northern Rocky Mountain Section, Midcontinent Ecological Science Center, Fort Collins, Colo. 11 pp.

Singer, F. J., M. B. Coughenour, T. Johnson, and R. Cates. 1993. Population estimation, plant interactions, forage biomass, and offtake and carrying capacity estimation of elk in the Estes Valley. Proposal to National Park Service, Denver, Colo. 23 pp.

Peer Reviews for Rocky Mountain National Park:

Smith, M., J. Dodd, and J. Mitchell. 1994. Unpublished peer reviews of Rocky Mountain National Park elk research study plan to National Biological Service (now USGS-BRD), Fort Collins, Colo.

Hobbs, N. T. 1994. Unpublished peer reviews of Rocky Mountain National Park elk research study plan.

Unsworth, J., G. C. White, D. C. Bowden, S. Steinert, and G. Schoenveld. 1994. Correction of elk counts in and near Estes Park and Rocky Mountain National Park: A problem analysis. April 26, 1994 memorandum, National Biological Survey (now U.S. Geological Survey), 4512 McMurry Avenue, Fort Collins, Colo.

Peer Reviews for Yellowstone National Park:

Garton, E. O., and D. Goodman. 1986. Recommendations concerning northern Yellowstone elk: Aerial survey and population analysis. November 26, 1986, Yellowstone National Park files. 14 pp.

McNaughton, S. J., J. Detling, and L. Wallace (D. Houston ex officio member). 1986. Yellowstone elk research: Consultant's report. Yellowstone National Park files. 3 pp.

species diversity. Three peer-reviews of the initial study design were obtained in 1994 (Hobbs 1994; Smith et al. 1994; Unsworth et al. 1994). A statistical analysis of field data collected from 1968–1992 was completed (Zeigenfuss et al. 1999). A mid-study science based assessment of vegetation management goals for elk winter range was conducted (Berry et al. 1997). Modifications to the original plan were made to meet some of the concerns of Berry et al. (1997) and through introspection by the study team investigators and unanswered questions brought out during analysis of the first two years of data. These modifications included: (1) an analysis of long-term climate trends to evaluate vegetation changes; (2) one more year of offtake measures to reduce high variances observed during years one and two; (3) measures of biomass and offtake in town since it became obvious after two years of research that more elk were wintering in town than in the park; (4) the earlier proposed study of total N cycle and sustainability was funded by the USGS-NRPP fund program; (5) the long-term trends of willows were determined from sequences of aerial photos and GIS analyses; and (6) a population-based estimate of K for elk (ecological carrying capacity) in both town and in the park was conducted. A regional study of the effects of elk on plant species diversity with a multi-scale perspective was funded for a number of study sites, that opportunistically included the RMNP winter range (Stohlgren et al. 1999). Thus, all of the elements of the ideal research study were achieved, including: (a) a study design and plans were prepared at the outset; (b) these were peer-reviewed; and (c) a mid-study assessment and changes in response to that assessment were accomplished.

The study also included additional characteristics of a strong research initiative. There was an emphasis on an ecosystem approach to the study (Fig. 1), including the involvement of an interdisciplinary study team of six scientists. Riparian willow and upland shrub communities were selected for the focus of field data collection. A GIS was used to randomly locate study plots on a landscape scale. A strong experimental nature to the project was developed, in order to control for a large number of potentially confounding variables (Fig. 2). Sixteen exclosures were constructed to exclude herbivory to simulate the effects of no elk, and clipping treatments were conducted inside portions of exclosures to simulate more elk or the invasion of moose to the system (Fig. 2). The question of whether willows and wet site herbaceous vegetation were responding to elk herbivory alone, or also responding to climate change, hydrologic changes, beaver declines, succession, or other factors was addressed. Check dams were used to add water to some study plots to simulate hydrologic change, in particular the return of beaver and their dams. Prescribed burns were conducted inside and outside upland shrub exclosures to evaluate fire effects. Measurements were also made within three 35-year old exclosures to assess the effects of herbivore exclusion over a longer time period.

First, a brief executive summary keynotes the key findings. In the following sections, we present the methodology and findings for each study of the various ecosystem components. The final section summarizes model findings against various ecological paradigms to assist staff of RMNP in their assessment of the appropriate number of elk. In a separate modeling report, the SAVANNA modeling effort uses a GIS-based, spatially-explicit model to draw together the findings of these various study components into a single, predictive ecosystem model (Coughenour 2001).

The chronological timetable of the planning for this initiative and the peer reviews and study elements are presented in Table 2. The specific measures that were gathered during this study, number of plots, and measures at each plot and the rationale for each measure or group of measures is presented in Table 3.

Literature Cited

Berry, J., D. Decker, J. Gordon, R. Heitschmidt, D. Huff, D. Knight, W. Romme, and D. Swift. 1997. Science-based assessment of vegetation management goals of elk winter range, Rocky Mountain National Park. Environment and Natural Resources Policy Institute, Colorado State University, Fort Collins, Colo. 16 pp.

Coughenour, M. 2001. A spatially explicit ecosystem model (SAVANNA) of different ungulate management scenarios. Final report to U.S. Geological Survey and National Park Service.

Hess, K. 1993. Rocky times in Rocky Mountain National Park. University Press of Colorado, Niwot. 167 pp.

Hobbs, N. T. 1994. Unpublished peer reviews of Rocky Mountain National Park elk research study plan.

Packard, F. M. 1947. A study of the deer and elk herds of Rocky Mountain National Park, Colorado. Journal of Mammology 28:4–12.

Smith, M., J. Dodd, and J. Mitchell. 1994. Unpublished peer reviews of Rocky Mountain National Park elk research study plan.

Stohlgren, T. J., L. D. Schell, and B. V. Heuvel. 1999. How grazing and soil quality affect native and exotic

plant diversity in Rocky Mountain grasslands. Ecological Applications 9:45–64.

Unsworth, J., G. C. White, D. C. Bowden, S. Steinert, and G. Schoenveld. 1994. Correction of elk counts in and near Estes Park and Rocky Mountain National Park: A problem analysis. April 26, 1994 memorandum. National Biological Survey (now U.S. Geological Survey), 4512 McMurry Avenue, Fort Collins, Colo.

Zeigenfuss, L. C., F. J. Singer, and D. Bowden. 1999. Vegetation responses to natural regulation of elk in Rocky Mountain National Park. Biological Science Report USGS/BRD/BSR-1999-0003. U.S. Government Printing Office, Denver, Colo. 23 pp.

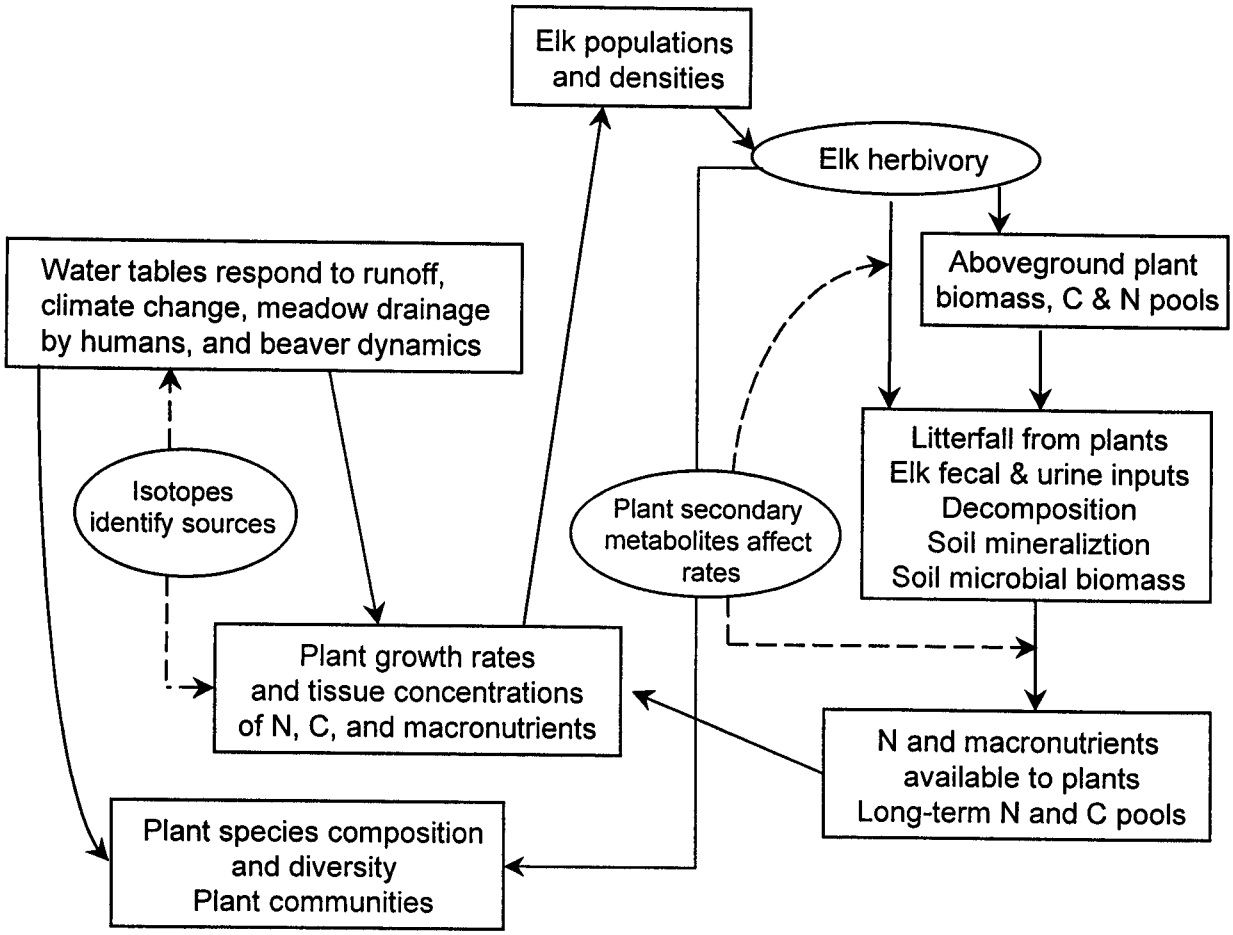

Fig. 1. Ecosystem approach to the study of elk abundance and herbivory effects on winter range of Rocky Mountain National Park, Colorado, 1994–1999.

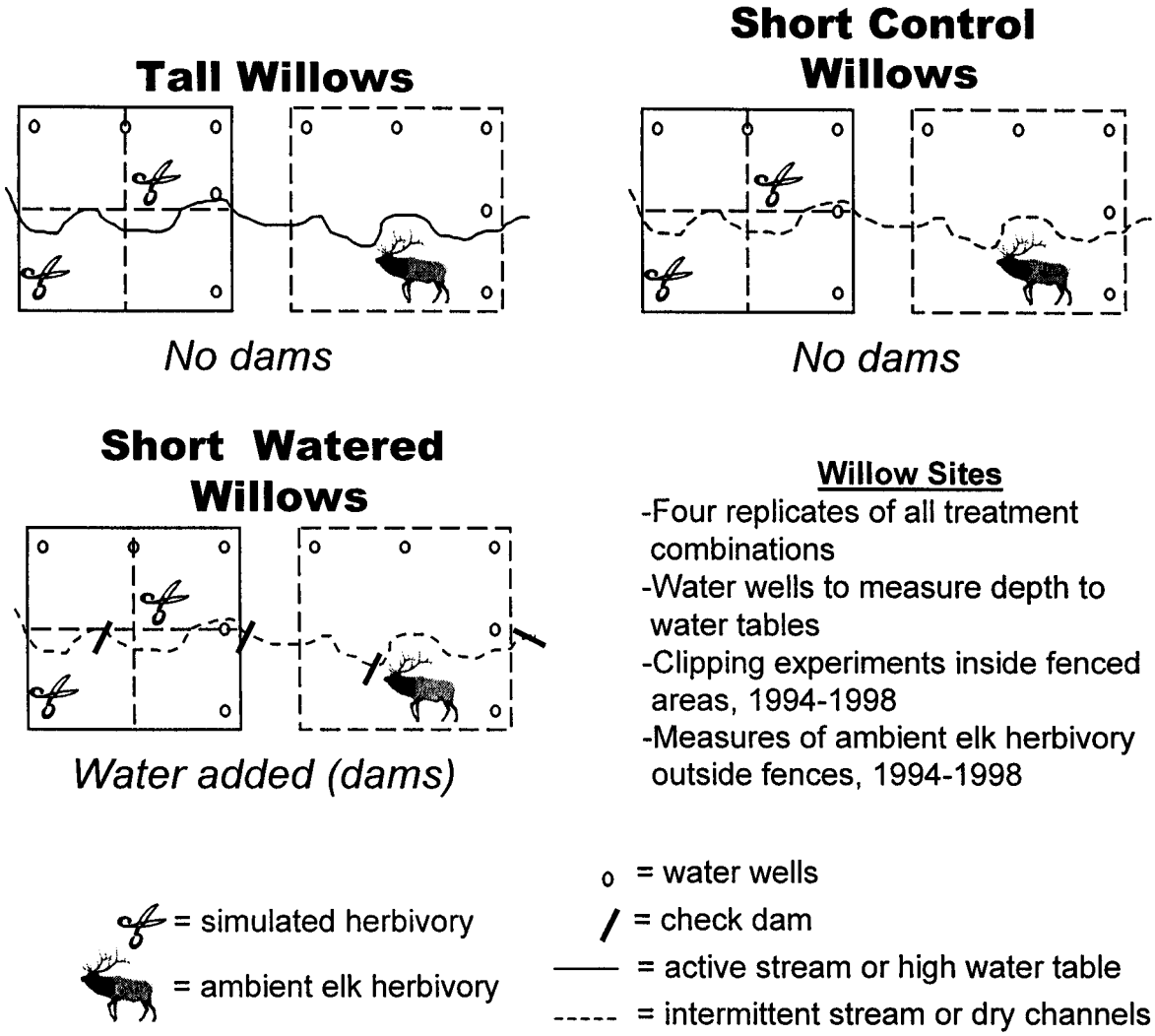

Fig. 2. Experimental design used to study impacts of elk herbivory and water availability on elk winter range of Rocky Mountain National Park, Colorado.

Table 2. Chronology of significant events, Rocky Mountain National Park elk ecology study, 1992–2001.

1992	Final report on 25 years of elk research submitted by D. Stevens.
1993	Problem analysis and review of earlier work by F. Singer. Parallel proposals to NBS (now USGS-BRD) and NPS written by F. Singer.
1994	Three peer reviews of study designs. Pre-treatment vegetation biomass data collected. Exclosures and treatments put in place.
1995	Radiocollars placed on 73 elk. Dams and clipping treatments put in place.
1995–1997	Prescribed burns conducted. Post-treatment field data collected by BRD, NREL (Natural Resource Ecology Lab), and NPS crews.
1997	Berry et al. (1997) science-based assessment of vegetation goals occurs at mid-study. Study modifications according to Berry et al. (1997) and research team analysis.
1998	Additional year of offtake measures, climate analysis, and sustainability study.
1999	Release of statistical analysis of 25 years of long-term vegetation responses (Zeigenfuss et al. 1999).
2001	Planned release of final BRD-NREL report to the park on 1994–1999 study.

Table 3. Study variables measured, locations and rationale for their measurements, Rocky Mountain National Park, Colorado, 1994–1999.

Variable measured	Rationale for studying the topic	Location
Nutrient processes	Nitrogen is single most important factor to plant growth	
Biogeochemical processes		
% nitrogen in plants and soil		
Nitrogen mineralization rates		12 new willow exclosures
Elk fecal/urine deposition rates		Three 35-year-old exclosures
Nutrient flows and inputs and outputs of N by elk vs. litterfall		
Production and offtake	Evaluate effects on plants and to determine allowable use.	16 new exclosures Three 35-year-old exclosures
Plant species composition	To evaluate whether species shifts to exotics or grazing-resistant species are occurring.	16 new exclosures One 35-year-old exclosure
Water table levels	To examine whether hydrological manipulations were successful at increasing water on sites, and to correlate water availability to plant growth and biogeochemistry.	12 new willow exclosures
Plant physiological measures	To evaluate impact of herbivory on water balance and individual plant processes.	12 new willow exclosures
Plant water balance		
Photosynthesis and carbon gain		
Secondary metabolites	Plants which are heavily browsed may return to a juvenile phase, producing higher concentrations of defensive compounds, and thereby influencing nitrogen cycling through quality of litterfall.	12 new exclosures One 35-year-old exclosure
Elk movements, population dynamics, and census		
Elk density in park and town	To correlate with plant abundance.	Winter range on park east slope and town of Estes Park
Elk trends and density-dependent population processes	To determine if elk will regulate their numbers.	Throughout elk winter range in the park and the town of Estes Park.
Estimate ecological carrying capacity (food-limited) for elk in town and park	To determine at what density elk numbers might stabilize.	Throughout elk winter and summer range in the park and the town of Estes Park.
Macronutrient analysis	To determine whether herbivory, water availability, or fir affect nutrient concentrations in plants consumed by elk.	16 new exclosures Three 35-year-old exclosures
Measures of willow cover, morphology, seed production, and demography	Seed production may decrease under high levels of herbivory. Willow morphology may shift to shorter, more compact crowns under high herbivory levels.	12 new exclosures One 35-year-old exclosure